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III.

DOES THE SENSATION OF MOVEMENT ORIGINATE IN THE JOINT?

By W. B. PILLSBURY.

Since Goldscheider's work on the 'Muscle Sense' there seems to be very general agreement that the joint is the only or by far the most important source of the sensations that inform us that we have moved the members of the body. Almost no question has been raised during the decade that has elapsed as to the absolute completeness and exactness of his results. During the last few years, however, the conviction has been growing upon the writer that some of this work needs revision or extension, and that the dominant part which is ascribed to the joint in the complex is not definitely proved to be deserved.

Goldscheider's analysis of the sensations received during passive movement makes it consist (1) of the sensations that arise from the rubbing of articular surfaces, together with wrinkling of the capsule; (2) strain upon the tendons of one set of muscles and relaxation of the tendons of the antagonists, and (3) change in the form of the muscles. A striking divergence in the facts of consciousness from what this analysis suggests is seen in the majority of subjects who work with the sensation for the first time in that the movement seems to be noticed first in the wrist or fore-arm, or even in the tips of the fingers. A possible explanation of this fact in terms of Goldscheider's theory might be offered if we considered the sensation in the wrist merely the result of an associative projection of the joint sensation to the part that is most concerned in the movement. This would bring it under the same category as the projection of sensations to the tip of the pen in writing, or to the end of the cane in walking. This was the explanation that was offered to the students, and that for some time seemed entirely satisfactory. On one occasion, however, it was suggested to two students who were suspicious about this explanation that they pass an induction current through the wrist and see if it had any effect. It was supposed that there would be no effect of any kind, but on the contrary it was found that there followed nearly as marked a decrease in sensibility as when the current was passed through the elbow itself. This observation was confirmed on several subjects and with several

successive classes until there seemed to be no longer any doubt that it would be profitable to work over the field again in spite of the general acceptance that is accorded to Goldscheider's conclusions.

Experiments were begun in November, 1900, and continued until the following January. Mr. Bair (B.), Mr. Stevens (S.) and the writer (P.) acted as subjects. All had had some previous psychological training. Experiments were made upon the elbow and knee joints only. The apparatus used was the ordinary passive movement apparatus, a hinged board to support the arm which was raised by a cord that passed over a pulley fixed in the top of an upright. To avoid the unevenness in speed that is necessarily connected with moving the board by hand we arranged to lift it by an electric motor. The speed of the motor was reduced by a worm gear and a series of pulleys. An ordinary clutch in an old bit of shafting served to interrupt the movement of the board without stopping the motor. The connection between shafting and arm board was made by an elastic cord. This served admirably to reduce the jerk at starting. The slack was taken up gradually, and the movement began almost imperceptibly. When once started the movement was at a constant rate. A pointer in the end of the arm board moved over a millimeter scale on the upright that supported the pulley and served to measure the amount of the movement of the arm.

In the first series of experiments the subject sat with the arm upon the board, with the elbow joint just over the hinge, the clutch was adjusted to start the board, and a signal was given as the arm began to rise. This time for giving the signal was adopted after several trials because it was the only one that permitted a constant interval to elapse between the time of giving the signal and the entrance of the sensation into consciousness. It could not be given when the clutch was adjusted to start the movement because it was impossible to keep the amount of slack to be taken up a constant. The movement was so slow (about 20' per second) that it ordinarily took about two seconds for the movement to progress far enough to be noticed. The first series of experiments were taken with the arm normal, then a series was taken with the induction current passing through the elbow, a third with the current passing through the wrist, and finally several series with both elbow and wrist anæsthetic. In each case the current was passed as nearly as possible directly through the joint to be experimented upon. The results are collected in Table I.

In the Table the first pair of columns gives the results with the normal arm, the second those with the current through the elbow, the third with the current through the wrist, and the

TABLE I.

SUB- JECT.	NORMAL.		CURRENT TO ELBOW.		CURRENT TO WRIST.		WRIST AND ELBOW.	
	No.	M.	No.	M.	No.	M.	No.	M.
B.	118	33'	81	1° 45'	70	1° 28'	85	2° 8'
S.	163	51'	76	2° 30'	68	1° 43'	76	6° 27'
P.	179	26'	68	1° 50'	68	2° 2'	70	2° 24'

last with the current through both wrist and elbow. The first column in each pair gives the number of experiments, the second, the average just noticeable movement. It will be seen that in every case there is a very noticeable diminution in the sensitivity to movement at the elbow when the current is passed through the wrist. In one case the minimal movement is considerably less than when the elbow joint is anæsthetised; in a second case is slightly less, and in a third case is slightly greater, but in no case is the average movement necessary to produce a sensation less than twice as great as that required in the normal arm. A confirmation of the result is found in the fourth series of experiments in the fact that when the current was passed through both joints at once there was a marked decrease of sensitivity as compared with either of the other conditions. Any suspicion that these results may be due to suggestion or may be artefacts of the method of procedure is removed by the facts that the sensitivity decreased constantly as the series of experiments proceeded, would increase again if for any reason the experiment was resumed after temporary interruption with the current cut off, and that the anæsthesia persisted with diminishing force for some time after the current had stopped.

The same series of experiments was repeated with the knee joint. In these experiments a very similar apparatus was used as for the elbow. The board used was long enough to accommodate the lower leg, the subject lay face down upon a table with the knee-joint just over the hinge. The lower leg was supported by the knee and the toes so that no other parts were in contact with the apparatus. The position was uncomfortable, and it was, therefore, necessary to give the subjects frequent rests to prevent excessive fatigue. The discomfort, however, would affect all results in the same degree, and so would not detract from the relative correctness of the results. The differences are also too large and too constant to be accounted for by any error of this kind.

The experiments were repeated for the knee in very much the same order and with the same results as in the preceding case. The results are shown in Table II below.

TABLE II.
Movement of Knee Joint.

SUB- JECT.	NORMAL.		TOE ON SPONGE.		CURRENT THROUGH TOE		KNEE.		ANKLE.		KNEE AND ANKLE.	
	N.	M.	N.	M.	N.	M.	N.	M.	N.	M.	N.	M.
B.	239	1° 15'	—	—	—	—	85	2° 46'	97	2° 8'	86	3° 12'
S.	128	1° 27'	59	1° 18'	133	1° 18'	126	2° 46'	115	2° 46'	—	—
P.					123	41'	150	2° 22'	105	2° 11'		

Here, too, anæsthesia of the joint distal to the one moved had a marked effect in decreasing the sensitivity of the latter. The results are again usually not so great as in passing the current through the moved joint, but are not so very different from it. In the one case in which the two joints were anæsthetised at the same time there is again a marked increase over the effect upon either alone. For P. and S. this series was not taken as the other two were in complete agreement, and did not seem to need confirmation.

Incidentally in the series with S. we obtained an interesting comparison of the sensitivity of the skin and the deeper lying sense organs. S. noticed during the first series of normal experiments that there was a sensation coming from the skin of his toes, and feared that he might be making his judgment in terms of the tactual rather than of the kinæsthetic sensations. When the experimenter watched carefully it was seen that as the member was raised the toes were forced upward along the board rubbing the skin as they moved. This movement at times amounted to as much as two millimeters. To guard against this source of error the toe was first placed upon a dry sponge which moved along the board and saved the toes, which it supported, from the rubbing. It will be seen in the second column of Table II that the only result of this arrangement was actually to decrease the least noticeable movement. Fearing that there might still be some sensation from the skin that enabled the judgment to be made, the sponge was moistened and connected with one pole of the induction coil, another electrode was placed on the other side of the toes, and the current passed through. It will be seen from the table again that the result under these conditions gave exactly the same average as in the preceding case. The sensation from the skin, then, has apparently absolutely no influence upon the judgment. Under these conditions the limen for the tactual is either higher than or identical with the limen for the kinæsthetic sensations. The subject's impression that the judgment was in terms of the skin must have been due to the fact that the board was not

stopped quickly enough after he had made his judgment to prevent overstepping the limen for the tactual sensations as well as for the kinæsthetic, and the distinction between the sensations that came before and those that came after the judgment could not be clearly drawn. These experiments with current through the toe would also remove any possibility of the effect of the induction current being due to the distracting effect of the pain. Here we find the same strength of current actually resulting in an increased rather than a decreased sensibility, if we are to draw any conclusion at all from differences so slight.

The experiments upon B. had already been made before these observations, and in the light of them it did not seem necessary to discard the earlier ones. The experiments on P. were all made, assuming the results obtained with the current through the toe as the standard of reference.

Our results then go to show very definitely that the sensibility to movement in elbow or knee is decreased nearly as much by passing a current through the ankle or wrist as by passing it through the joint that is concerned. Our next question is as to how this fact can be explained in the light of what we know of the sensory nerve supply of the different parts, and how they can be brought into harmony with the results of Goldscheider in the same field.

It seems evident at once that the conclusions of Goldscheider that sensation of movement is mainly due to the excitation of the sensory endings in the joints by the rubbing of joint surfaces cannot be accepted without further investigation and modification. Certainly the nerves at the elbow are not likely to be rendered less sensitive by the passage of the current through the wrist, and on his premises there seems no possibility of any other explanation.

Let us turn to the anatomical facts in relation to the distribution of sensory nerves and see what light these cast upon the subject. The undisputed facts as to endings that may be concerned is first that there are highly developed sensory endings thickly scattered in the tendons, particularly in the zone of transition from muscle to tendon (Huber and DeWitt,¹ Golgi,² and others), that there are sensory endings in the tissue of the muscle, and that Pacini corpuscles are found embedded in adipose tissue between the tendons and muscles, and are particularly frequent in the neighborhood of the joints (Rauber).³

¹A Contribution on Nerve Terminations in Neuro-tendinous Organs: Jour. of Comp. Neurology, Vol. XII, pp. 159, ff.

²*Sui nervi nei tendini dell'uomo*, etc. Memor. della R. Accad. delle Sc. di Torino; Serie II, Tomo XIII, 1880.

³Untersuchungen Ueber das Vorkommen u. Bedeutung d. Vater-schen Körper, München, 1865.

The sensory innervation of the joint is not so definitely made out nor so free from disputed points. The statement so frequently made in the text-books of physiology and psychology that the joints or joint surfaces are richly supplied with sensory endings seems to have grown out of Rauber's discovery that there were Pacini corpuscles in the neighborhood of the joints. This statement was, apparently, at first taken to mean indefinitely inside or outside of the joint capsule, then within the capsule, and, finally, on the joint surfaces. At least we could nowhere find any definite statement that sensory nerves were found on those surfaces, and where any authority was cited for the nerve supply of the joints the reference was to Rauber. Goldscheider gives no authority for his statement, and says definitely: 'Eine anatomische Untersuchung der Innervation der Gelenkenden wäre wünschenswerth.' Ivanhow¹ found sensory endings in the fasciæ and the capsules of the joints, but this seems to be the only well established histological evidence of sensory endings in the joints themselves.

In the same article Goldscheider² attempted to prove physiologically that the joint surfaces were sensitive, but with poor success. He exposed the joint surfaces in frogs and rabbits, and stimulated them by pressure and heat, in the hope that he might excite respiratory reflexes. His results were of a negative kind. He did call out reflexes when the bone was cut away to expose the marrow, but with the uninjured joint surfaces there was no definite response, that could not be interpreted as due to the transmission of the stimulation to the periost or to the marrow. He concludes, "Dass die Gelenkfläche selbst empfindlich sei, hat durch die Versuche nicht erwiesen können," but adds, "Aber auch ohne dieselbe darf wohl die Berichtigung, die Gelenkenden als Substrat einer Sensation anzusehen, bereits anerkannt werden." The grounds upon which he rests this conclusion in the earlier article are: first, the fact that the sensitivity is reduced by passing an electric current through the joints, then that all the other possible sense organs may be eliminated,—the skin because a superficial anæsthesia does not diminish the sensitivity to movement; the muscle and tendon because there is practically the same limen for all positions of the limb while the variations in the condition of the muscle must take place more rapidly in one position than in another. The first argument we are prepared to deal with later; that the skin does not serve as the organ, may pass without comment, while the argument that it

¹ On Nerve Endings in the Connective Tissue Capsules and fasciæ of mamalia (Russian). Dissertation, Kasan, 1893.

² Ueber die Empfindlichkeit d. Gelenkenden: Gesamm. Abhandlungen II. pp. 282, ff.

is neither muscle nor tendon, seems to have taken into consideration only the flexors, and to have forgotten the extensors, which would be affected in the opposite way in all respects, and serve to counteract any irregularities to be expected from the flexors alone, and also to have overlooked the muscles that were attached about the joint which do not serve to bend it. The evidence in favor of the joint surfaces as the seat of the sensation then is reduced to the fact that the sensitivity of the joint is reduced when the current is passed through it.

Our results cannot easily be explained in terms of Goldscheider's hypotheses, but can easily be brought into line if we assume that the sensation of movement originates in the tendon organs or in the Pacinian corpuscles which Rauber described. This becomes clearer from a glance at the arrangement of muscles and tendons that run from elbow to wrist, and from knee to ankle. Many of the large muscles, both flexor and extensor, have their origin above the elbow on the lower end of the humerus and their insertions at the lower end of the radius or ulna, in the metacarpi or even in the phalanges of the fingers. The upper tendons of all these muscles cross the elbow joint, and the lower tendons are thickly gathered together at the wrist. Any movement of the arm must tend to relax the tension on one set of muscles and tendons, and to increase that on the other set. Very similar relations hold for the lower leg. The sensations that are produced by these changes in tension would come from about the elbow and knee in part, but also in part from the wrist and lower forearm, and from ankle and lower leg. Anæsthesia of either set of tendons would then be expected to produce a decreased sensitiveness to movement, as we found in our experiments. Furthermore, we should expect that the current through the elbow and knee would have the more marked effect, as the tendons at the lower ends of the muscles begin to appear well up on the forearm and lower leg, and so a smaller portion of their length would be affected by the current, and, secondly, the tendons at the insertions of the muscles of the upper arm and thigh, biceps and triceps, *e. g.*, would be affected at the elbow and knee, and not at the wrist or ankle. Another set of organs to be affected are the Pacinian corpuscles described by Rauber. These are most numerous about the joints, and any change in the tension upon the muscles and tendons would also change the pressure upon them. Altogether, then, our results would be satisfactorily and completely explained on the assumption that it is the tendon and muscle organs, not the joint surfaces, that are the source of the sensations of movement.

If it is still insisted that the joints are sensitive and originate the sensation, it is only possible to explain the reduction of

sensitivity by the current through the wrist and ankle on the assumption that the muscles and tendons acted as cords, and that the displacement at the elbow or knee produced an increase or decrease in the pressure of joint surface upon joint surface at the wrist and ankle. Even if the joint were extremely sensitive it is hardly conceivable that the tendons could transmit sufficient energy to produce a noticeable effect there without exciting the delicate sense organs in their tissue. Particularly would this be the case if we consider the probability that there would be only a change in the disposition of the pressure upon the surfaces rather than a change in the amount of the pressure.

Looked at from every side, then, it seems very difficult to avoid the conclusion that the part of the sensation of movement which originates in the wrist is due to stimulation of the tendon organ. If we are forced to this conclusion in the one case, it certainly seems easier in the light of the doubt that surrounds the innervation of the joint to assume that the sensation from the elbow is also a tendinous or muscular sensation rather than one from the joint. The forces that stimulate the lower tendon are at work in even greater degree in the upper, and they are alone sufficient to account for the known effects. Any bringing in of joint sensation would at the least be entirely gratuitous. What part the sensory endings in fasciæ and capsule may play does not appear. However, from the fact that they are relatively less developed than the tendon and muscle organs, and that they are probably less favorably situated for stimulation, it would seem probable that they have a minor rôle.

SUMMARY.

We find that the sensitivity of the joints is decreased by induction currents through wrist and elbow as well as by currents through the joints in question. This fact, together with the lack of anatomical evidence that the joints have sensory endings, makes it probable that the sensation of movement is derived mainly from the tendon and muscle rather than, as Goldscheider thought, from the joint.